Overview of Mars Technology Program

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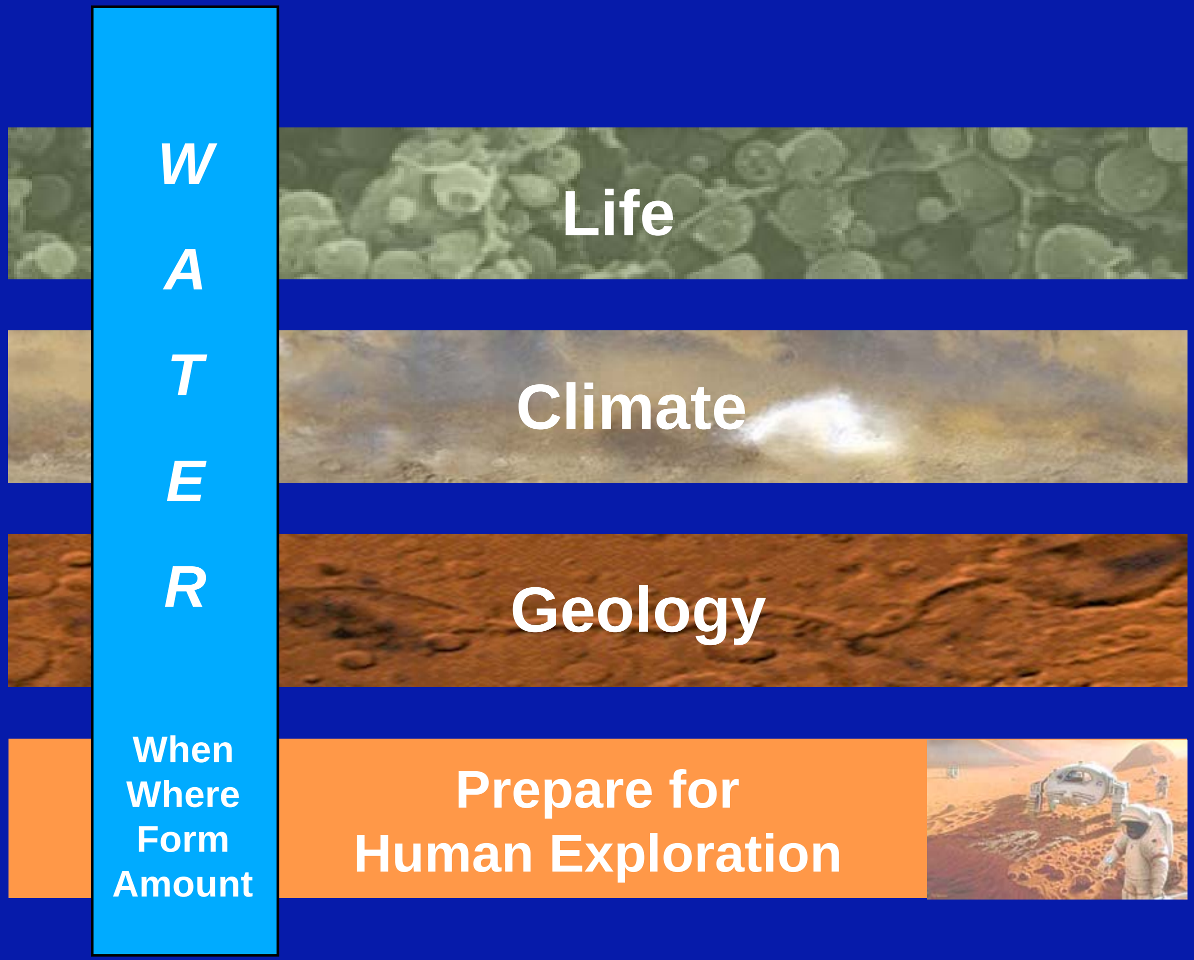
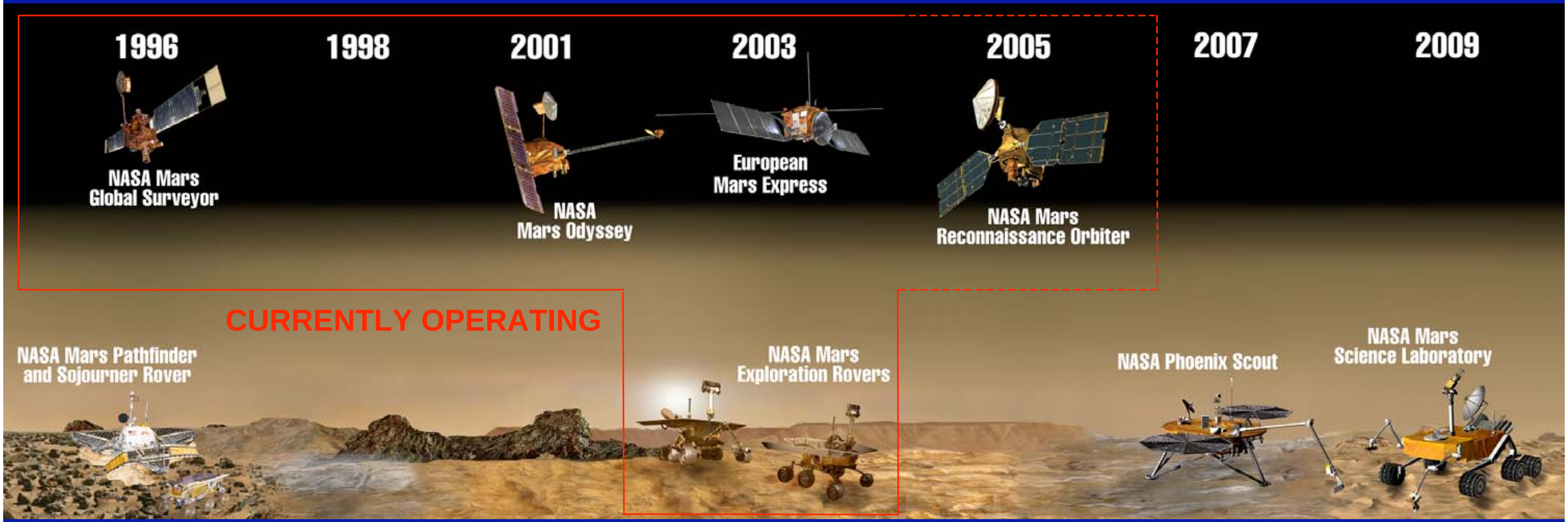
Outline

- *Mars missions, past, present, and future*
- *Objectives of technology program*
- *Elements of technology program*
- *Program metrics*
- *Major accomplishments*

Mars Science Strategy



Mars Exploration Program



Mars Exploration Program
Next Decade Plan

2007 | **2009** | **2011** | **2013** | **2016**

Mapped near surface ice

Phoenix
(Phase C/D)

Search for organics in modern habitat

Scout

Discovered persistent surface water

MSL
(Phase B)

Search for habitable zones and biosignatures

AFL

Look for past or present life

OR

MidRovers

Explore geologic diversity

Discovered methane, source unknown

MSO

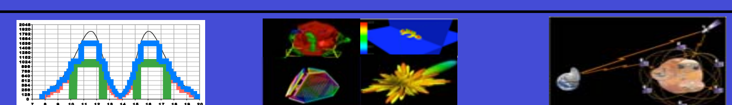
Identify biologic or geologic source of methane, characterize evolution of atmosphere

Continuing discussions on ‘18/’20:

- Tentative candidates are Scout for ‘18 and Network for ‘20

Technology Program Objectives

- *Develop a technology program for future Mars missions*
- *Develop required technologies for future Mars missions*
- *Develop technologies to enable new types of missions currently not possible*
- *Acquire technologies for Mars missions via competition and when appropriate through direct assignments*

Capabilities	Examples
Land more payload mass on higher altitudes more accurately	
Access to sites with terrain too complex for landing current rovers	
Increase mobility and autonomy	
Access the subsurface and acquire samples for in-situ analysis	
Enable improved science instruments	
Protect Mars via planetary protection techniques	
Enable Mars sample return	
Develop capabilities for in-situ sample acquisition, preparation, and distribution systems	
Develop proximity telecommunication technologies	

Mars Technology Program (MTP)

- *MTP is an integral part of Mars Program (all funds are provided by Mars Program). It is managed at JPL within the Mars Exploration Program for NASA.*
- *MTP funds technology developments that are specific to Mars*
- *MTP leverages other technology programs such as:*
  - *In-Space Propulsion Technology Project*
  - *IS Program*
  - *ESMD technology program*
  - *ASTEP, PIDDP, ASTID, ESTC, etc.*
- *Program is comprised of four elements:*

Focused Technology

Base Technology

Studies

Technology Testbeds

Technology Planning Process

Science Office ⇄ ***Science Goals, etc.*** ⇄ ***Advanced Studies Office*** ⇄ ***Technology Needs*** ⇄ ***Technology Office***

- *MEPAG*
- *SAG'S*

Candidate Program/
Mission Sequences

- *Mission Concepts*
  - *Technology*
  - *Mission Development*
  - *Mission Ops*
  - *LV*

Tech Plans

- *Focused Tech Program Plans*
- *Base Tech Plans*

Review by
Mars Program Systems Engineering Team (MPSET)

Focused Technology

- ***Focused Technology*** *is aimed at advancing enabling technologies to TRL 6 by the PDR of specified missions.*
- *Missions manage focused technologies, with MTP oversight, with flight project discipline, including cost, schedule, and reviews.*
- *Technology plans are aligned as project's needs are consolidated*
- *Technologies deemed no longer required for a particular mission are continued if significant investments were made and future missions are beneficiaries.*
- *Focused technology programs have start and end dates and allocated funds*
- *Technology validations are performed within focused technology tasks*
- *Tasks are directed or competed with the aim of maximizing probability of infusion to missions*

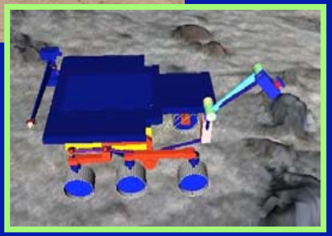
Base Technology

- ***Base Technology*** *addresses technology advances for multiple missions including technologies that will enable new mission types*
- *Base technologies are not in the critical path of NASA baselined Mars missions*
- *Technology acquisition is via NASA NRAs*

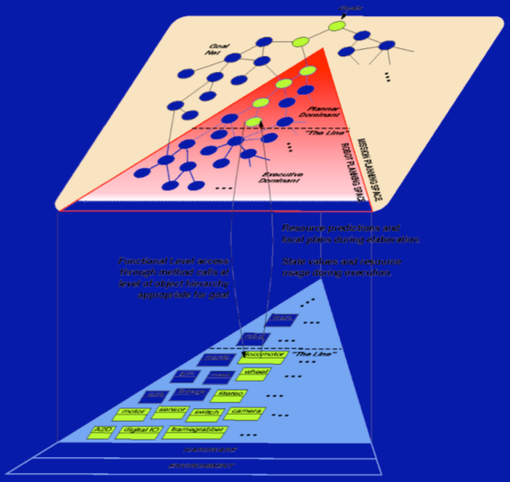
Studies

- *Technology planning is also supported by studies for better understanding of:*
  - *State of the art*
  - *Determining feasibility and technical approach*
  - *Cost and schedule*
- *Many of these studies are co-funded and co-managed by MTP and Advanced Studies Office*
  - *Examples are:*
    - *Pin-point landing*
    - *Increased mass landing on Mars*
    - *Night driving*
    - *Aeroshell measurement sensors*
    - *MSR technology*
    - *Etc.*

Technology Testbeds



- *Technology Testbeds are physical or software testbeds designed to integrate component technologies to develop capabilities and provide a facility for validation*
- *Examples are:*
  - *CLARAty/Dsend/ROAMS software environments*
  - *Technology rovers (at Ames/ JPL/ CMU)*
  - *Drill specific planning and control software*
  - *Controlled environment for testing drilling technologies*
  - *Rover facility for MIDP instrument testing in the field*
  - *Mars Yard (one time investment, funds were provided by Mars Program)*



Program Performance

- Three metrics have been selected to assess MTP performance:
  - Technology infusion into Mars missions
    - Focused Technology
    - Base Technology
  - Technology Readiness Levels (TRL)
    - TRL advancements
  - Publications, NTRs, Patents

Major Accomplishments

- *Four new technologies are being infused into MER, if successful, this brings the total technologies infused into MER to 14*
- *All three focused technologies developed for MRO have been successfully infused to the project*
- *Three technologies are infused into Phoenix Project (mostly from Base technology program)*
- *MSL focus technology has been very successful in developing relevant technologies that have very high probability of infusion. Current best estimate is that 60% funds used in MSL technology will be used by the mission.*

MER

	Technology	Funding Source	Description	PI/Technologist
1	Long Range Science Rover	NASA (Code R and MTP)	Provides increased traverse range of rover operations, improved traverse acuracy, landerless and distributed ground operations with a large reduction in mass	Samad Hayati Richard Volpe
2	Science Activity Planner	NASA (Code R and MTP)	Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists	Paul Backes Jeff Norris
3	FIDO: Field Integrated Design and Operations Rover	NASA (MTP)	Developed TRL 4-6 rover system designs, advancing NASA capabilities for Mars exploration; demonstrated this in full-scale terrestrial field trials, Integrated/operated miniaturized science payloads of mission interest, coupling terrestrial field trials to flight requirements	Paul Schenker Eric Baumgartner
4	Manipulator Collision Prevention Software	NASA (MTP)	Computationally efficient algorithm for predicting and preventing collisions between manipulator and rover/terrain.	Eric Baumgartner Chris Leger
5	Descent Image Motion Estimation System (DIMES)	NASA (Code R and MTP)	Software and hardware system for measuring horizontal velocity during descent, Algorithm combines image feature correlation with gyroscope attitude and radar altitude measurements.	Andrew Johnson Yang Cheng et al.
6	Parallel Telemetry Processor (PTeP)	NASA (Code R and MTP)	Data cataloging system from PTeP is used in the MER mission to catalog database files for the Science Activity Planner science operations tool	Mark Powell Paul Backes
7	Visual Odometry	NASA (MTP)	Onboard rover motion estimation by feature tracking with stereo imagery, enables rover motion estimation with error < 2% of distance traveled	Larry Matthies Yang Cheng
8	Rover Localization and Mapping	NASA (MTP)	An image network is formed by finding correspondences within and between stereo image pairs, then bundle adjustment (a geometrical optimization technique) is used to determine camera and landmark positions, resulting in localization accuracy good for travel up 1 km	Ron Li Clark Olson et. al.
9	Grid-based Estimation of Surface Traversability Applied to Local Terrain (GESTALT)	NASA (Code R and MTP)	Performs traversability analysis on 3-D range data to predict vehicle safety at all nearby locations; robust to partial sensor data and imprecise position estimation. Configurable for avoiding obstacle during long traverse or for driving toward rocks for science analysis	Mark Maimone
10	Lithium-Ion Batteries	NASA (Code R and MTP), Air Force (AFRL)	Significant mass and volume savings (3-4 X) compared to the SOA Ni-Cd and Ni-H2 batteries.	Richard Ewell Rao Surampudi
	New Technology Infusion (in Progress, passed flight upload gate review, Jume 2006)			
11	Automated instrument placement	MTP Base (JPL)	Enable final target approach and instrument placement within single command cycle	Chris Leger
12	Automated tracking to approach designated rocks autonomously	MTP Base (JPL/ARC)	Enable flight demonstrations of 10-m target tracking on Martian surface using MER navcam stereo cameras.	Won Kim
13	On-Board global path planning	MTP Base (CMU/JPL)	Smarter negotiation around extended obstacles (added capability to GESTALT)	Arturo Rankin Tony Stenz
14	Autonomous science to detect dust devils	IS Program, NMP, MTP	Onboard detection and tracking of dust devils and clouds	Steve Chien Ronald Greeley

MRO

Electra

Developed and delivered an EM as part of Electra Payload project. This constitutes MTP's first successful hardware development that will be used by baselined and future Mars missions.

Electra radio is currently on MRO and will be used on MSL

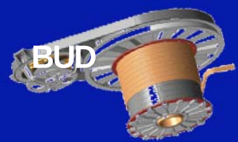
*The **Optical Navigation Camera** (ONC) developed by the Mars Technology Program (PI, Steve Synnott) completed its experiment objectives.*

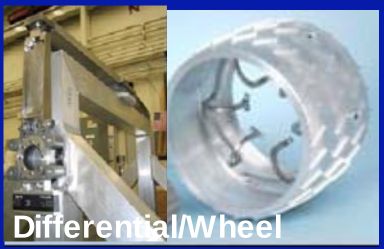
- *–The Optical Navigation Camera experiment successfully acquired and processed 480 images during MRO's approach phase.*
- *–Analysis of the data residuals indicates that objective of nav error to be less than 1-2 km has been achieved.*
- *–Data analysis is in progress and will complete this FY*

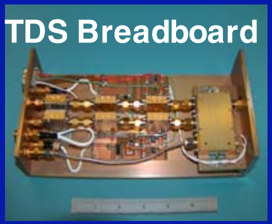
MSL

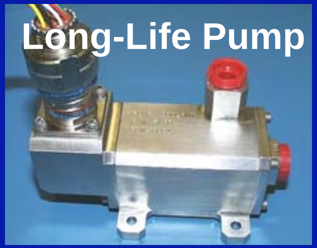
Program Objectives

- *Develop technology for MSL Entry, Descent, and Landing (EDL) and Surface Systems which will enable new capabilities including:*
  - *Precision Guided Entry*
  - *Robust Touchdown System*
  - *Long-lived Mobility Asset*
  - *Efficient Surface Ops*
  - *Sample Acquisition & Distribution*
- *Mature technologies to TRL 6 by MSL PDR*









Contributions of MSL Focused Technology Program to MSL

- *MSL FT $84M investment (FY03-FY06) successfully retired significant technology risks*
  - ***EDL HW:*** Mars Lander Engine (MLE), Terminal Descent Sensor (TDS), Bridle/Umbilical/DRL (BUD)
  - ***EDL SW:*** Guided-entry algorithms, Terminal descent algorithms, V&V tools (POST2 & DSENDS)
  - ***Surface Systems HW:*** Cold-temperature actuators/electronics, Long-life/high-temp fluid loops, Coring tool, Landing-capable light-weight wheel/suspension/differential
  - ***Surface Systems SW:*** Improved uplink planning system (APSS), Simulation tools (MP-AvSim & ROAMS)
- *Major design contributions made during MSL Phase A/B include:* Skycrane concept, Preliminary EDL performance analysis, Aeroheating environments testing, TPS testing/database, and SA/SPaH concept
- *Overall maturity of critical technologies and design concepts enables short Phase B for MSL*

Significant Accomplishments—Mars Lander Engine

- ***Completed "Development" program for Mars Lander Engine (including new throttle valve assembly)***
  - *Completed Design Verification Test (nearly equivalent to full flight qualification test program)*
  - *3 development engines tested—DEV3R meets all performance requirements with margin*
  - *Resolved performance anomaly during DEV2 hot-fire testing – effect of cold (0°C) propellant greater than expected*
- ***SOA: Viking engine***
  - *Updated to SOA materials and catalyst bed retention for MSL*
  - *MSL single nozzle modification produces higher performance*
  - *New "cavitating" throttle valve design achieves <1% to >100% thrust range*

Mars Lander Engine

Viking Engine

MSL Throttle Valve Assembly

Significant Accomplishments—Terminal Descent Sensor

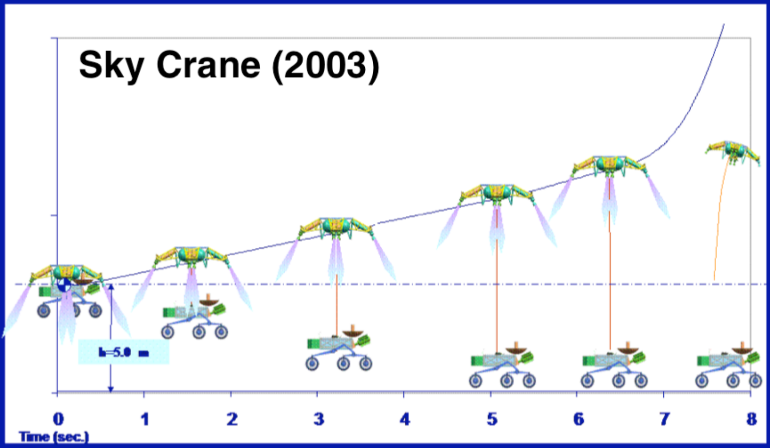
- ***Completed fabrication and testing of Terminal Descent Sensor Breadboard***
  - *Ka-band radar with electronics and real-time processing heritage to MSLFT Phased Array Terrain Radar program (FY03-FY04)*
  - *Better than 10cm/s velocity and 10 cm range performance*
  - *Matured design and operations concept for MSL flight unit development*
- ***SOA: Wide-beam altimeter/velocimeter (Phoenix) or helicopter velocity sensor***
  - *Performance improved by more than 10x over Phoenix sensor and 2x better than helicopter sensors (which lack ranging)*
  - *Ka-band narrows beamwidth (reducing velocity & ranging errors) and improves velocity precision*

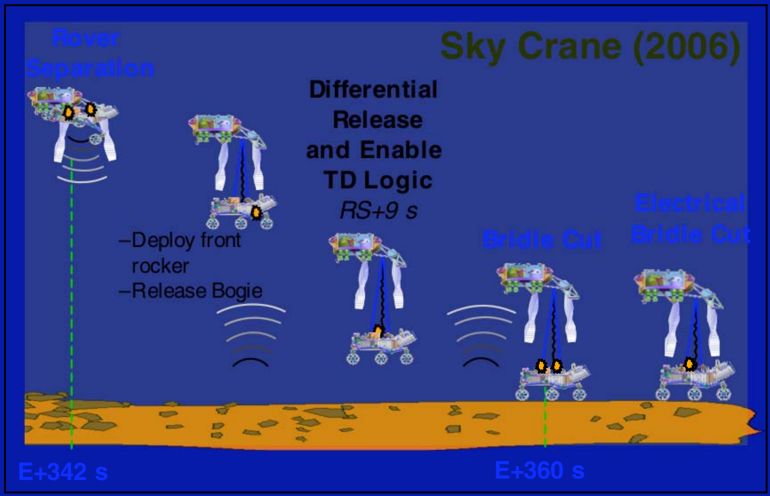
TDS Breadboard Rack

Ka-band Front End

Significant Accomplishments—Skycrane Landing

- ***Matured the Skycrane concept (in close collaboration with Project)***
  - *Successfully realized a robust Skycrane design through comprehensive analysis/testing and numerous external/peer reviews*
  - *Contributed to designs of testbeds including development of 1 d.o.f. motion control and mini-TDT*
- ***SOA: Airbag or Legged Landing***
  - *Airbag landing can not support MSL size rover*
  - *Legged landing poses complications with engine shutdown, landing on sloped terrain, and egress*





Significant Accomplishments—Heat Rejection Systems

- ***Completed fabrication and testing of long-life/high-temperature fluid loops***
  - *Demonstrated reliable operation of CFC-11 fluid loops at 100 °C required for MSL mission*
  - *Chemical compatibility of fluid loop materials with CFC-11 for the MSL mission duration*
  - *Developed technologies for MSL fluid loop components (mechanical fittings, thermal control valve) to provide longer and reliable life for MSL fluid loops*
- ***SOA: MPF and MER fluid loop***
  - *MPF and MER fluid loop do not meet the temperature and life required for MSL mission*
  - *MPF and MER fittings leak rate is three orders of magnitude higher and thermal control valve causes small temperature cycling of the loop*

MSL HRS Life Testbed

MSL Long-Life Pump

Test Loop for High Temperature Testing

Base Technology

Eight areas have been identified as high priority technology areas for Mars missions

Proximity Telecom/Navigation	Rover Technology
Subsurface Access	Planetary Protection
Advance EDL	Low Cost Mission Technologies
Mars Science Instruments	Advanced Electronics

Currently, 95 tasks are within the Base Program

Mars Technology Program

Example TRL Evaluation form

TRL 4: Component/subsystem validation in laboratory environment	MTP Technology Readiness Level Evaluation for Hardware TRL 6: System/subsystem model or prototype demonstration in a relevant environment	TRL 5: Component/subsystem validation in relevant environment

Technology Product Description	Starting TRL	Investment $	Cog. MTP Task Mgr	Organization	MTP Element	Element Manager	Date
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

STARTING TRL JUSTIFICATION	[illegible]

OBJECTIVE CRITERIA	Req'd	Design assumptions	Comments
1 Functional and environmental requirements of the flight system	YES	[illegible]	
2 Description of relevant environment	YES	[illegible]	

EVALUATION CRITERIA	Req'd	Anticipated Status/Results at Delivery	Current Status/Results	Comments
1 Design drawings	YES	[illegible]	[illegible]	
4 Interface specifications	5/6	[illegible]		
5 Mechanical analysis (including analytical models)	5/6	[illegible]		
6 Electrical analysis (including analytical models)	5/6	[illegible]		
7 Thermal and packaging analysis (including analytical models)	5/6	[illegible]		
8 Power analysis (including analytical models)	YES	[illegible]	[illegible]	
9 Mass (and CG) analysis	YES	[illegible]	[illegible]	
10 Non-flight-like parts list	6	[illegible]		
11 Availability of flight-quality equivalents for electronic parts	6	[illegible]	[illegible]	
12 Reliability analysis	6	[illegible]		
13 Functional test (analytical models and telemetry included)	YES	[illegible]	[illegible]	
14 Environmental Functional test	5/6	[illegible]		
15 Compliance of tested hardware to the requirements and drawings	YES	[illegible]	[illegible]	
16 Failure history and failure trend	5/6	[illegible]		
17 Extent of changes required for prototype	5/6	[illegible]		
18 QA paperwork for the delivered hardware (optional)	6	[illegible]		
19 Delivery of end-item data package to MTP	YES	[illegible]		

TRL assessment: [illegible]	Cog. MTP Task Manager Signature	Element Manager Signature	Technology Manager Signature	MTP Program Manager Signature

For more information…

- *All technology tasks are documented in the on-line Technology Information System (OTIS/TDA), accessible at JPL:*

  https://tdaweb.jpl.nasa.gov/tda/

- *New MTP website provides abstracts and a point of contact for each technology task among other information*

  http://marstech.jpl.nasa.gov

- *MTP Docushare accessible by permission*

  http://mtp-lib.jpl.nasa.gov